SECTION 2

Objectives

- Describe the short-term and long-term process of the carbon cycle.
- Identify one way that humans are affecting the carbon cycle.
- List the three stages of the nitrogen cycle.
- Describe the role that nitrogen-fixing bacteria play in the nitrogen cycle.
- Explain how the excess use of fertilizer can affect the nitrogen and phosphorus cycles.

Key Terms

carbon cycle
nitrogen-fixing bacteria
nitrogen cycle
phosphorus cycle

The Cycling of Matter

Everything is made of matter. *Matter* is anything that has mass and takes up space. Organisms need both energy and matter to live, grow, and reproduce. Energy and matter are constantly moving through ecosystems. The *law of conservation of energy* states that energy cannot be created or destroyed. Energy changes forms. For example, producers change light energy to chemical energy in sugars. The *law of conservation of matter* states that matter cannot be created or destroyed. Instead, matter moves through the environment in different forms. Ecosystems do not have clear boundaries, so some energy and matter can leave them. In this section, you will read about three cycles by which matter and energy are reused—the carbon cycle, the nitrogen cycle, and the phosphorus cycle.

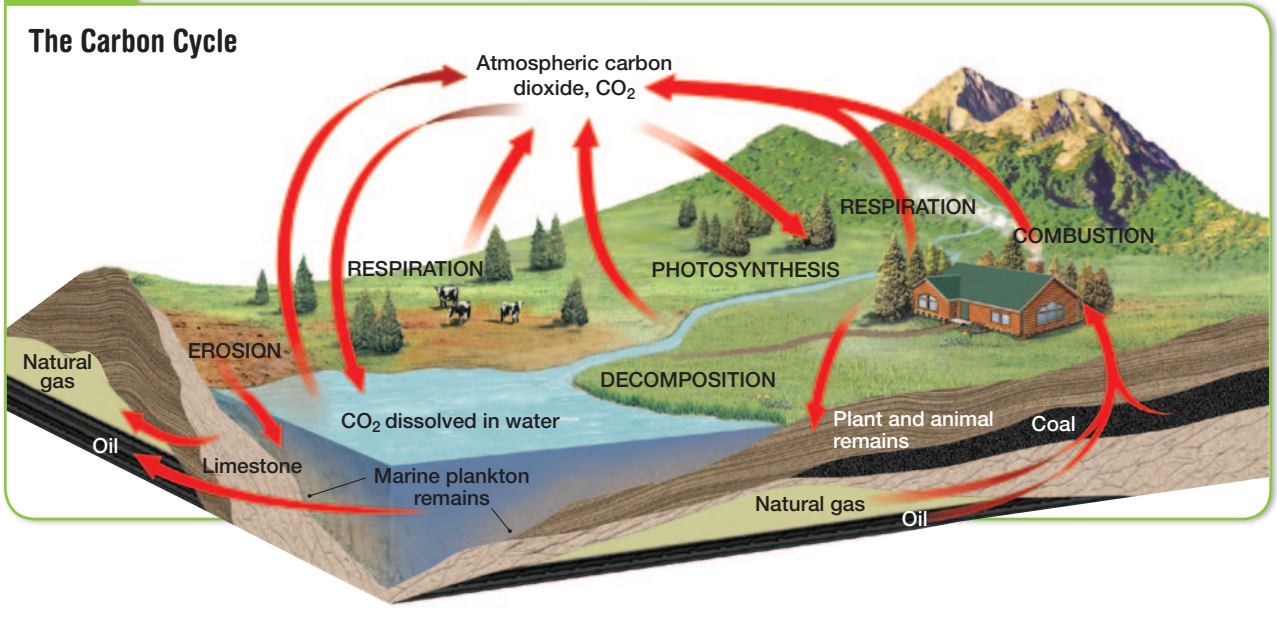
The Carbon Cycle

Carbon is an essential component of proteins, fats, and carbohydrates, which make up all organisms. The **carbon cycle** is a process by which carbon is cycled between the atmosphere, land, water, and organisms. As shown in **Figure 2.1**, carbon enters a short-term cycle in an ecosystem when producers, such as plants, convert carbon dioxide in the atmosphere into carbohydrates during photosynthesis. When consumers eat producers, the consumers obtain carbon from the carbohydrates. As the consumers break down food during cellular respiration, some of the carbon is released back into the atmosphere as carbon dioxide. Producers also release carbon dioxide during cellular respiration.

Some carbon enters a long-term cycle. For example, carbon may be converted into *carbonates*, which make up the hard parts of bones and shells. Bones and shells do not break down easily. So, over millions of years, carbonate deposits have produced huge formations of limestone rocks. Limestone is one of the largest *carbon sinks*, or carbon reservoirs, on Earth.

FIGURE 2.1

The Carbon Cycle



Some carbohydrates in organisms are converted into fats, oils, and other molecules that store energy. The carbon in these molecules may be released into the soil or air after an organism dies. These molecules can form deposits of coal, oil, and natural gas underground. The deposits are known as *fossil fuels*. Fossil fuels are made up of carbon compounds from the bodies of organisms that died millions of years ago.

How Humans Affect the Carbon Cycle

When we burn fossil fuels, carbon is released into the atmosphere as carbon dioxide. Cars, factories, and power plants rely on fossil fuels to operate. In the year 2009, vehicles, such as the truck in **Figure 2.2**, were the source of just over one-third of all carbon dioxide emitted in the United States. Each year, about 8.4 billion metric tons of carbon dioxide are released into the atmosphere by the burning, or combustion, of fossil fuels and the natural burning of wood in forest fires. About half of this carbon dioxide remains in the atmosphere. As a result, the amount of carbon dioxide in the atmosphere has steadily increased.

Increased levels of carbon dioxide in the atmosphere are the major contributor to climate change. Carbon dioxide is a greenhouse gas. *Greenhouse gases*, including water vapor and other gases, absorb and re-radiate infrared energy, warming Earth. Plants absorb some of the carbon dioxide, but scientists estimate that, each year, over a billion metric tons of carbon dioxide dissolves into the ocean, a carbon sink. The increase in carbon dioxide can lower the pH, which can impact marine organisms.

FIGURE 2.2

Carbon Emissions This truck releases carbon into the atmosphere when it burns fuel to operate.

CRITICAL THINKING

Relate Explain how the carbon emission from this truck enters and exits producers, such as the trees shown in this photo.

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QUICKLAB

Make Every Breath Count

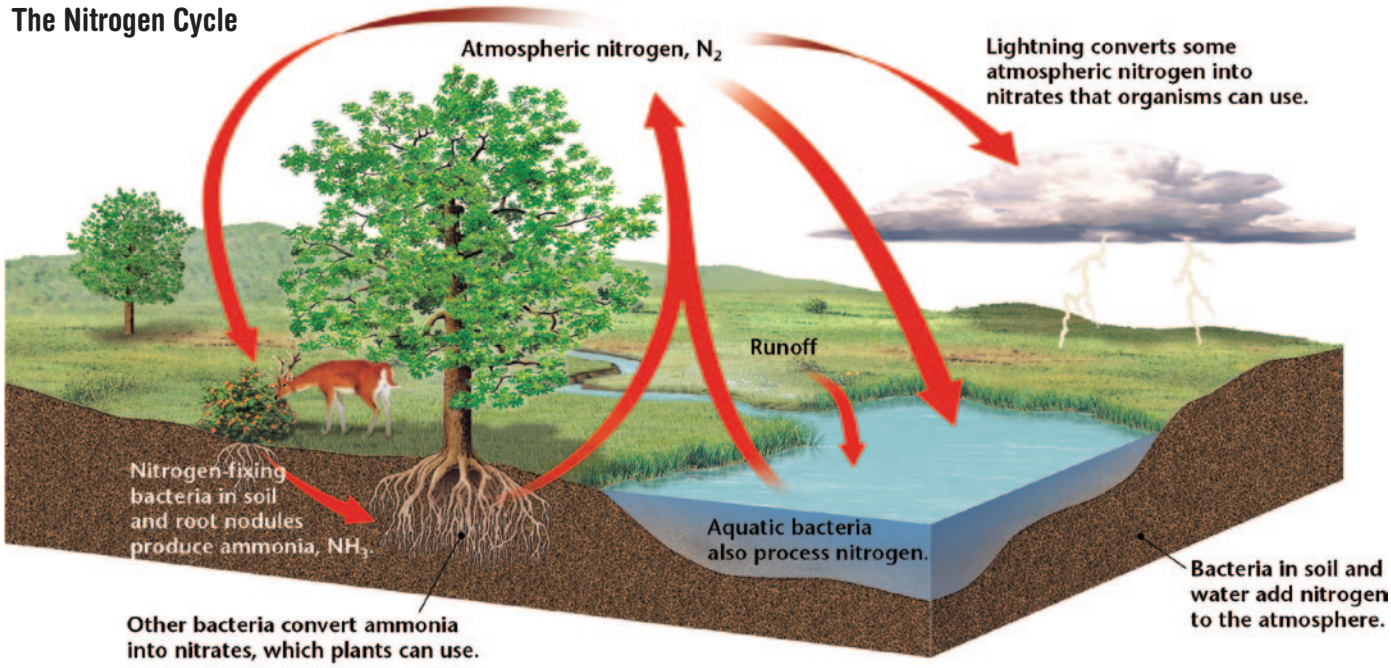
Procedure

1. Pour 100 mL of water from a graduated cylinder into a 250 mL beaker. Add several drops of bromthymol blue to the beaker of water. Make sure you add enough to make the solution a dark blue color.
2. Exhale through a straw into the solution until the solution turns yellow. (CAUTION: Be sure not to inhale or ingest the solution.)
3. Pour the yellow solution into a large test tube that contains a sprig of Elodea.
4. Stopper the test tube, and place it in a sunny location.
5. Observe the solution in the test tube after 15 minutes.

Analysis

1. What do you think happened to the carbon dioxide that you exhaled into the solution?
2. What effect do plants, such as the *Elodea*, have on the carbon cycle?

FIGURE 2.3



The Nitrogen Cycle

All organisms need nitrogen to build *proteins*, which are used to build new cells. Nitrogen makes up 78 percent of the gases in the atmosphere. However, most organisms cannot use atmospheric nitrogen. It must be altered, or fixed, before organisms can use it. Only a few species of bacteria, called **nitrogen-fixing bacteria,** can fix atmospheric nitrogen into a useful form called ammonia. All other organisms depend upon these bacteria to supply nitrogen. As shown in **Figure 2.3**, nitrogen-fixing bacteria are a crucial part of the **nitrogen cycle,** a process in which nitrogen is cycled between the atmosphere, soil, and organisms. Some nitrogen enters the soil through fixation by lightning. Energy in lightning breaks apart nitrogen molecules in the air, which recombine with oxygen molecules to form nitrogen oxide. Rainwater combines with nitrogen oxide to form nitrates that enter the soil.

Nitrogen-fixing bacteria, shown in **Figure 2.4**, live in nodules on the roots of plants called *legumes*. Legumes include beans, peas, and clover. The bacteria use sugars provided by the legumes to produce nitrogen-containing compounds such as nitrates. The excess nitrogen fixed by the bacteria is released into the soil. Some nitrogen-fixing bacteria live in the soil. Plants that do not have nitrogen-fixing bacteria in their roots get nitrogen from the soil. Animals get nitrogen by eating plants or other animals, both of which are sources of usable nitrogen.

Decomposers and the Nitrogen Cycle

In the nitrogen cycle, nitrogen moves between the atmosphere and living things. Some of the nitrogen that cycles from the atmosphere to living things is released to the soil with the help of bacteria. These decomposers are essential to the nitrogen cycle because they break down

FIGURE 2.4

Nitrogen-Fixing Bacteria The swellings on the roots of this soybean plant are called *nodules*. Nitrogen-fixing bacteria, shown magnified at the top right, live inside the nodules of some plants.

wastes, such as urine, dung, leaves, and decaying plants and animals and return the nitrogen from these wastes to the soil. If decomposers did not exist, much of the nitrogen in ecosystems would be stored forever in wastes, corpses, and other parts of organisms. After decomposers return the nitrogen to the soil, bacteria transform a small amount of the nitrogen into nitrogen gas, which then returns to the atmosphere. So, most of the nitrogen that enters an ecosystem stays within the ecosystem. It cycles between organisms and the soil, and is constantly reused.

ECOFACT

Minerals in Your Mouth

Phosphorus is the 11th most abundant element in the Earth's crust and occurs naturally as phosphate in the mineral apatite. Apatite can exist in igneous, metamorphic, and sedimentary rocks as well as in your teeth and bones.

The Phosphorus Cycle

The element phosphorus is part of many molecules that make up the cells of living organisms. For example, phosphorus is needed to form bones and teeth in animals. Plants get the phosphorus they need from soil and water, while animals get their phosphorus by eating plants or other animals that have eaten plants. The **phosphorus cycle** is the movement of phosphorus from the environment to organisms and then back to the environment. This cycle does not include the atmosphere because phosphorus rarely occurs as a gas.

Phosphorus enters soil and water in many ways, as shown in **Figure 2.5**. When rocks erode by weathering, some phosphorus dissolves as phosphate in soil, water, and groundwater. Plants absorb phosphates in the soil through their roots. Phosphorus also leaches into soil and water when phosphate is excreted in waste from organisms and when organisms die and decompose. Some phosphorus also washes off the land and ends up in bodies of water. Many phosphates are not soluble in water, so they sink to the bottom of water bodies, and accumulate as sediment. Over many thousands of years, the sediments become rock.

FIGURE 2.5

The Phosphorus Cycle

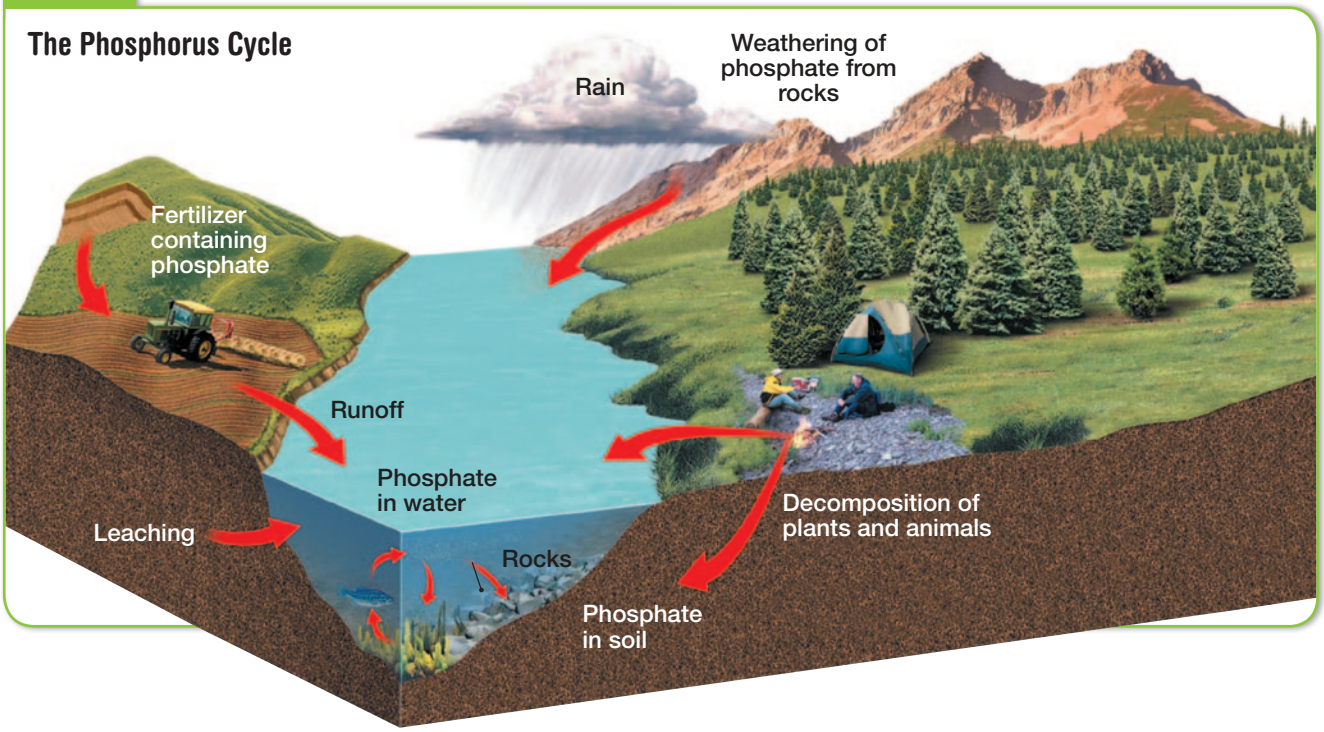


FIGURE 2.6

Fertilizers and Algal Blooms More than 30 percent of fertilizer may flow with runoff from farmland into nearby waterways. Large amounts of fertilizer in water can cause an excessive growth of algae (right).

(l) ©Nigel Cattlin/Photo Researchers, Inc.; (r) ©G.R. Roberts Photo Library

Fertilizers and the Nitrogen and Phosphorus Cycles

People often apply fertilizers to stimulate and maximize plant growth. Fertilizers contain both nitrogen and phosphorus. If excessive amounts of fertilizer are used, the fertilizer can enter terrestrial and aquatic ecosystems through runoff. Excess nitrogen and phosphorus in an aquatic ecosystem or nearby waterway can cause rapid and overabundant growth of algae, which results in an *algal bloom*. An algal bloom, as shown in **Figure 2.6**, is a dense, visible patch of algae that occurs near the surface of water. Algal blooms, along with other plants and the bacteria that break down dead algae, can deplete an aquatic ecosystem of important nutrients such as oxygen. Fish and other aquatic organisms need oxygen to survive.

Humans add so much nitrogen to the environment, that we have doubled the amount of fixed nitrogen entering ecosystems on land. This can lead to long-term problems in soil fertility because other nutrients are lost. Plants that are adapted to low nitrogen levels no longer thrive.

CHECK FOR UNDERSTANDING

Recognize How do algal blooms harm aquatic ecosystems?

Section 2 Formative Assessment

Reviewing Main Ideas

1. **Describe** the two processes of the carbon cycle.
2. **Describe** how the burning of fossil fuels affects the carbon cycle.
3. **Explain** how the excessive use of fertilizer affects the nitrogen cycle and the phosphorus cycle.
4. **Explain** why the phosphorus cycle occurs more slowly than both the carbon cycle and the nitrogen cycle.

Critical Thinking

5. **Making Comparisons** Write a short paragraph that describes the importance of bacteria in the carbon, nitrogen, and phosphorus cycles. What role do bacteria play in each cycle?
6. **Applying Ideas** What is one way that a person can help to reduce the level of carbon dioxide in the atmosphere? Can you think of more than one way?